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(54) **Power supply controlled to supply load current formed as sine wave.**

(57) A power supply basically includes a rectifying section (10) for rectifying a sinusoidal a.c. voltage, a switching section (11) for receiving a voltage output from the rectifying section, and a smoothing section (12) having a smoothing capacitor. The power supply is controlled to have a sinusoidal load current and for the purpose, includes as a feature a power source circuit having a first path for flowing current from the rectifying section to the smoothing section and a second path for flowing current from an inductor (15) of the switching section to the smoothing section, circuits (16, 17) for sensing the current flowing through the first path and forming a reference current with a target waveform based on the sensed current, circuits (18, 19, 20) for sensing the current flowing through the switching element and determining such a conduction ratio of the switching element as matching the waveform of the sensed current to the waveform of the reference current, and a control circuit (21) for sequentially controlling a plurality of switching elements connected in parallel on and off based on the determined conduction ratio.

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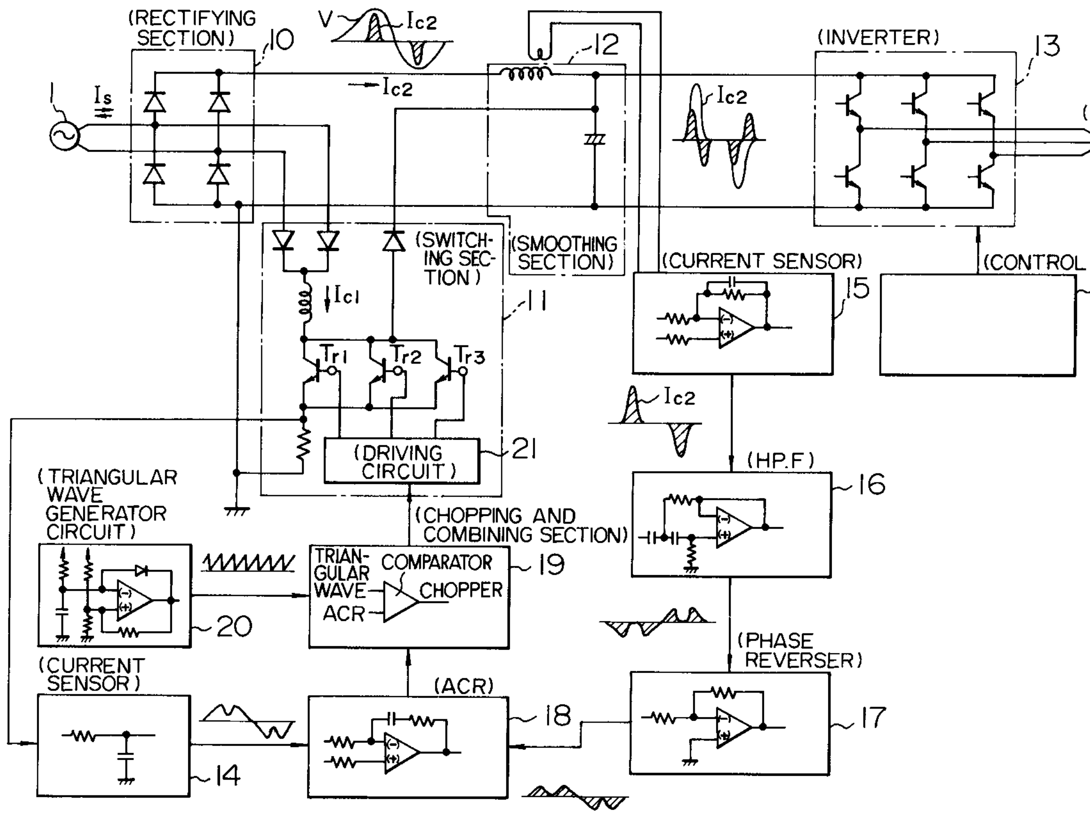

(RECTIFYING SECTION)
10
V
Ic2
Is
1
12
(INVERTER)
13
(MOTOR)
M
5
(SWITCHING SECTION)
(SMOOTHING SECTION)
Ic1
11
Tr1
Tr2
Tr3
(DRIVING CIRCUIT)
21
(CURRENT SENSOR)
15
(CONTROL CIRCUIT)
22
(HP.F)
16
(TRIANGULAR WAVE GENERATOR CIRCUIT)
20
(CHOPPING AND COMBINING SECTION)
TRIANGULAR WAVE
COMPARATOR
CHOPPER
ACR
19
(CURRENT SENSOR)
14
(ACR)
18
(PHASE REVERSER)
17

F I G. 1

BACKGROUND OF THE INVENTION

The present invention relates to a power supply for generating a d.c. voltage from a sinusoidal a.c. voltage such as a commercial a.c. voltage.

A power supply for generating a d.c. voltage from the commercial a.c. voltage is, in general, arranged to have a rectifier circuit for rectifying the a.c. voltage and a capacitor (smoothing capacitor) for smoothing the voltage output from the rectifier circuit. The voltage charged in the smoothing capacitor matches to the output voltage of the power supply.

However, the a.c. load current of the commercial a.c. power supply flows only if the a.c. voltage exceeds the voltage charged in the smoothing capacitor, that is, it does not flow if the a.c. voltage is equal to or lower than the charged voltage. Hence, the power supply having such arrangement cannot generate a sinusoidal voltage following the a.c. voltage but a pulsewise wave voltage containing lot of harmonic components. It results in remarkably lowering a power factor of the commercial a.c. power supply, thereby having an adverse effect on the other instruments connected to the commercial a.c. power supply.

To overcome this shortcoming, several kinds of power supplies have been conventionally proposed for enhancing a power factor of the commercial a.c. power supply by controlling load current to be similar to a sine wave. Some such conventional power supplies will be described later.

Fig. 13 is a circuit diagram showing a full wave rectifier disclosed in JP-B-63-22148. In Fig. 13, 1 is an a.c. power supply, 2 is an inductor, 3 is a full wave rectifier circuit, 4 is a smoothing capacitor, 5 is load, D_1 to D_6 are diodes, T is a transistor, and R_{S1} to R_{d1} are resistors for detecting current.

As shown, a sinusoidal a.c. supply voltage V_s supplied from the a.c. power supply 1 (see Fig. 14A) is supplied to the full wave rectifier circuit 3 composed of diodes D_1 to D_4 through the inductor 2. The supply voltage V_s is rectified in the full wave rectifier circuit 3 and then is smoothed in the smoothing capacitor, finally being applied to the load 5.

If only the foregoing operation is done, the a.c. power supply 1 serves to flow a.c. load current I_s only if the output voltage of the full wave rectifier circuit 3 is higher than the voltage charged in the smoothing capacitor 4. Hence, this a.c. load current I_s has a pulsewise waveform synchronized with a positive and a negative peaks of the a.c. supply voltage V_s as shown in Fig. 14(b), resulting in lowering a power factor of the a.c. power supply 1.

The arrangement shown in Fig. 13 provides the diodes D_5 and D_4 at the a.c. terminals of the full wave rectifier circuit 3. Those diodes D_5 and D_6 and the other diodes D_3 and D_4 compose an auxiliary full wave rectifier circuit and the output voltage of the auxiliary full wave rectifier circuit is chopped by a transistor T.

The transistor T is controlled on and off in response to a driving signal D_{rive} (see Fig. 14(f)) composed of an on/off signal C_h (see Fig. 14(d)) having a far higher frequency than the a.c. supply voltage V_s and a period control signal V_{SP} (see Fig. 14(e)) representing that the a.c. load current I_s is in the range of $-I_{SN} < I_S < I_{SP}$.

This arrangement results in allowing the a.c. load current I_s to flow based on the on/off operation of the transistor T even during the period when the output voltage of the full wave rectifier circuit 3 is lower than the voltage charged in the smoothing capacitor 4. As shown in Fig. 14(c), hence, the waveform of the a.c. load current I_s is closer to the waveform shown in Fig. 14(b). It results in improving a power factor of the a.c. power supply 1.

The resistors R_{s1} and R_{d1} for sensing the current in order to detect the change of load. Depending on the sensed output of the resistors, a generator (not shown) for the driving signal D_{rive} (see Fig. 14(f)) is controlled in order to adjust the period control signal V_{SP} (see Fig. 14(c)), therefore, the reference values I_{SP} and I_{SN} (Fig. 14(c)).

Fig. 15 is a circuit diagram showing a power supply employing a voltage doubler rectifier circuit, which is disclosed in JP-B-63-22148. In Fig. 15, 4A and 4B are smoothing capacitors, 6 is a voltage doubler rectifier circuit, D_7 to D_{10} are diodes, T_A and T_B are transistors, R_{s2} and R_{d2} are resistors for sensing current. The components corresponding to those shown in Fig. 13 have the same reference numbers.

In Fig. 15, the a.c. power voltage V_s output from the a.c. power supply 1 has a polarity indicated by an arrow. The a.c. load current I_s is flown from the a.c. power supply 1 to the inductor 2, the diode 7, the smoothing capacitor 4A, and the resistor R_{S2}, so that the smoothing capacitor 4A is charged with the voltage at the arrow-indicated polarity. If the a.c. supply voltage V_s is at an opposite polarity to the arrow, the a.c. load current I_s is flown from the a.c. power supply 1 to the resistor R_{s2}, the smoothing capacitor 4B, the diode D_8, and the inductor 2, so that the smoothing capacitor 4B is charged with the voltage at the arrow-indicated polarity.

It results in applying the addition of the charged voltages of the smoothing capacitors 4A and 4B into the load 5 as a d.c. supply voltage.

Like the power supply shown in Fig. 13, this power supply is not allowed to flow the a.c. load current I_s during the period when the a.c. supply voltage V_s is equal to or lower than the voltage charged in the smoothing capacitor 4A or 4B. Hence, the a.c. load current I_s has a pulsewise waveform shown in Fig. 14-(b).

To overcome this shortcoming, this power supply provides a circuit composed of both the diode D_9 and the transistor T_A connected in parallel to both the diode D_7 and the smoothing capacitor 4A and another circuit composed of both the diode D_{10} and the transistor T_B connected in parallel to both the diode D_8 and the smoothing capacitor 4B. If the a.c. supply voltage V_s is at a polarity indicated by an arrow, like the transistor T shown in Fig. 13, the a.c. supply voltage V_s is chopped by driving the transistor T_A on and off. If the a.c. supply voltage is at an opposite polarity to the arrow-indicated polarity, the a.c. supply voltage is chopped by operating the transistor T_B on and off.

The chopped power voltage results in having a waveform closer to a sine wave as shown in Fig. 14(c), thereby enhancing a power factor of the a.c. power supply 1.

Fig. 16 is a circuit diagram showing a power supply employing a voltage doubler rectifier circuit, which is disclosed in JP-B-62-45794. In Fig. 16, 2A and 2B are inductors, 7 is a current sensor, 8 is a hysteresis-added comparator, 9 is a driving circuit, and D_{11} to D_{14} are diodes. The components corresponding to those shown in Fig. 15 have the same numbers.

If the a.c. supply voltage V_s supplied from the a.c. power supply 1 is at a polarity indicated by an arrow, the a.c. load current I_s is flown from the a.c. power supply 1 to the inductors 2A, the diodes D_{11} and D_{12}, the smoothing capacitor 4A, and the inductor 2B, so that the smoothing capacitor 4A is charged with the voltage. If the a.c. supply voltage V_s is at an opposite polarity to the arrow-indicated polarity, the a.c. load current V_s is flown from the a.c. power supply 1 to the inductor 2B, the smoothing capacitor 4B, the diodes D_{14} and D_{13}, and the inductor 2A, so that the smoothing capacitor 4B is charged with the voltage. It results in applying addition of the voltages charged in the smoothing capacitors 4A and 4B as an a.c. supply voltage to the load 5.

An npn type transistor T_A is provided in parallel to the diode D_{12} and the smoothing capacitor 4A and a pnp type transistor T_B is provided in parallel to the diode D_{14} and the smoothing capacitor 4B. The hysteresis-added comparator 8 serves to compare the current flowing through the inductor with the current sensed by the current sensor 7. Based on the compared result, as shown in Figs. 17(a) and 17(b), the driving circuit 9 is fixed at "L" (low level) if the a.c. supply voltage V_s at the arrow-indicated polarity is equal to or higher than a predetermined level V_1 and is fixed at "H" (high level) if the a.c. supply voltage V_s at the opposite polarity to the arrow-indicated polarity is equal to or lower than a predetermined level V_2. The driving circuit 9 serves to produce a driving signal reversing "H" to "L" or vice versa from the other period high frequency. Based on the driving signal, the transistors T_A and T_B are controlled on and off.

As will be understood from the above description, if the a.c. supply voltage V_s has the arrow-indicated polarity and is equal to or lower than the voltage charged in the smoothing capacitor 4A, the transistor T_A is driven on and off for chopping the a.c. supply voltage V_s. If the a.c. supply voltage V_s is at the opposite polarity to the arrow-indicated polarity and is equal to or higher than the voltage charged in the smoothing capacitor 4B, the transistor T_B is driven on and off for chopping the a.c. supply voltage V_s.

Like the prior art shown in Fig. 15, therefore, this prior art can provide the a.c. load current I_s having a waveform closer to a sine wave as shown in Fig. 17(a) from the sinusoidal a.c. supply voltage V_s. It results in enhancing a power factor of the a.c. power supply 1.

The aforementioned prior arts, however, have the following problems.

(1) In the prior arts shown in Figs. 15 and 16, in case that the a.c. load current I_s is in the range from the reference value I_{sp} to I_{sn}, the waveform of the a.c. load current I_s is not constantly sinusoidal, because the waveform depends merely on the conduction ratio of the transistors T, T_A and T_B.

In the prior art shown in Fig. 16, depending on the magnitude of the load, the reference values change in a predetermined sinusoidal manner as shown by a broken line and a two-dot chain line shown in Fig. 17. Hence, the a.c. load current I_s can have a relatively excellent sinusoidal waveform, resulting in being able to reduce the harmonic wave and enhance a power factor. Since, however, the transistors T_A and T_B are controlled on and off depending on the above-mentioned reference values only, there exists a period when the switching is carried out at a high frequency without defining the chopping frequency. It results in causing an impractically large switching loss.

(2) In the aforementioned prior arts, as the switching frequency for the transistor T, T_A or T_B becomes higher, the waveform of the a.c. load current I_s is made more sinusoidal. In this case, however, the diodes D_1 and D_2 shown in Fig. 13, the diodes D_7 and D_8 shown in Fig. 15, or the diodes D_{12} and D_{14} shown in Fig. 16 may be delayed due to the forward-biased or reverse-biased state. Those diodes serve as a capacitive load when the transistors T, T_A and T_B are switched on. On the other hand, when the

transistors T, T_A and T_B are switched off, the inductor serves as an inductive load until the diodes enter into the forward-biased state, resulting in flowing excessive current, thereby increasing the switching loss. As a result, though the average a.c. load current is small, the transistors T, T_A and T_B are required to have large capacitance, because it is necessary to consider the switching loss.

(3) As will be apparent from the above description, to obtain a sinusoidal a.c. load current from the foregoing prior arts, as the on/off switching frequency for the transistor T, T_A or T_B becomes higher, the waveform of the a.c. load current becomes more precisely sinusoidal. Further, to reduce the inductor and the capacitor in size, it is necessary to perform the high-frequency switching operation. In the above-mentioned prior arts, however, it is necessary to perform the high-frequency switching operation of large current flown when the voltage is high for charging the smoothing capacitors, resulting in enlarging the switching loss. Hence, the conventional circuits have difficulty in performing the high-frequency switching operation.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a power supply which is capable of keeping the waveform of the a.c. load current sinusoidal at high accuracy and reducing the loss caused at the switching elements for chopping the a.c. supply current.

It is a further object of the present invention to provide a power supply which is capable of using a small-capacitance switching element as a switching element for chopping.

It is yet another object of the present invention to provide a power supply which is capable of reducing the loss of the switching element for chopping independently of the magnitude of the loss.

In carrying out the object, the power supply according to an aspect of the present invention takes the operating steps of sensing the current flowing through the switching element for chopping or the rectified a.c. load current, comparing the waveform of the current with the predetermined target waveform of a reference current, and controlling the switching element on and off at a conduction ratio at which both of the waveforms are matched to each other.

In carrying out the other objects, the power supply according to another aspect of the present invention is arranged to supply current to a smoothing section through a first passage led from the output of a rectifier section and a second passage leading through the inductor of the switching section and have a switching element restricted to flow the switching current only, for reducing the unnecessary switching loss.

For the switching element for chopping, a plurality of semiconductor swtiches or switching sections connected in parallel are provided. The on-state periods of those semicondcutor switches or switching sections are shifted on time in sequence, for the purpose of reducing the switching loss per one switching element.

As described above, the power supply according to the present invention operates to sense the current, compare the waveform of the sensed current with the predetermined target waveform of the reference current, and control the switching element on and off in a manner to match both waveforms to each other. Hence, the power supply can provide a quite accurate sinusoidal a.c. load current, resulting in greatly enhancing a power factor of the power supply.

Further, the power supply according to the present invention is capable of reducing the current flown through the switching element for chopping and the on-state voltage loss or switching loss in the switching element, resulting in reducing the capacitance of and the size of the switching element.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing a power supply according to an embodiment of the present invention;

Fig. 2 is a plot showing an effect of a high-pass filter included in the embodiment shown in Fig. 1;

Fig. 3 is a plot showing a current waveform for describing principle of the present invention;

Figs. 4 and 5 are block diagram showing a power supply according to another embodiment of the present invention;

Fig. 6 is a block diagram showing a power supply according to another embodiment of the present invention;

Fig. 7 is a plot showing the operation of the embodiment shown in Fig. 6;

Fig. 8 is a circuit diagram showing a power supply according to another embodiment of the present invention;

Fig. 9 is a plot showing a current waveform of each of the sections of the embodiment shown in Fig. 8;

Fig. 10 is a current waveform showing current flown when the transistor shown in Fig. 8 is switched on and off;

Figs. 11 and 12 are circuit diagrams showing a power supply according to another embodiment of the present invention, respectively;

Fig. 13 is a circuit diagram showing one example of a conventional power supply;

Fig. 14 is a plot showing a voltage, a current, and a signal waveform of each section shown in Fig. 13;

Figs. 15 and 16 are circuit diagrams showing another example of a conventional power supply, respectively; and

Fig. 17 is a plot showing the operation of the conventional power supply shown in Fig. 16.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Herein, embodiments of the present invention will be described as referring to the drawings.

Fig. 1 is a block diagram showing a power supply according to an embodiment of the present invention. 10 is a rectifier section, 11 is a switching section, 12 is a smoothing section, 13 is an inverter, 14 and 15 are current sensors, 16 is a high-pass filter, 17 is a phase inverter, 18 is an automatic current regulator (ACR), 19 is a chopping and combining circuit, 20 is a triangular wave generator circuit, 21 is a driving circuit, and 22 is a control circuit. The current waveform of each section is also shown in Fig. 1.

In Fig. 1, the a.c. supply voltage V_s output from the a.c. power supply 1 is rectified in the rectifying section 10 and is sent to the switching section 11. The switching section 11 is composed of an inductor and switching elements (Tr1, Tr2, Tr3). When the output voltage of the rectifying section 10 is higher than the voltage charged in the smoothing capacitor of the smoothing section 12, the current is flown from the rectifying section 10 to the smoothing capacitor through the inductor and is charged in the smoothing capacitor. The switching elements are controlled on and off by the driving circuit 21. When the switching element is controlled on, the a.c. load current I_s sent from the a.c. power supply 1 through the rectifying section 10 flows through the inductor and the switching element, so that the energy is stored in the inductor. When the switching element is switched off, the inductor emits the stored energy as a high voltage. It results in being able to flow current from the inductor through the smoothing section 12, the rectifying section 10 and the a.c. power supply 1.

Even if the output voltage of the rectifying section 10 is higher than the voltage charged in the smoothing capacitor, the switching element is controlled on and off. The part of the current output from the rectifying section 10 is flown to the smoothing capacitor through the inductor.

Assuming that the current flown into the smoothing section through the inductor is I_{c2} and the current supplied to the switching section 11 for chopping is I_{c1}, the load current I_s can be represented by the equation indicated below:

$$I_s = I_{c1} + I_{c2} \qquad (1)$$

The current sensor 15 serves to sense the current I_{c2} supplied to the smoothing section 12. The current I_{c2} contains lot of three or more degrees harmonics. From the current I_{c2}, only the harmonic components are extracted by the high-pass filter 16 having a higher cut-off frequency than the frequency of the a.c. supply voltage V_s. Fig. 2 shows the effect of the high-pass filter 16. In Fig. 2, each mark "O" indicates the component of the input current I_{c2} of the high-pass filter 16 and each mark "X" indicates the component of the output current of the high-pass filter 16. That is to say, the output current of the high-pass filter 16 is a result of attenuating the fundamental component having the same frequency as the a.c. supply voltage from the current I_{c2}.

In Fig. 3, I_1 is the fundamental component of the current I_{c2}, 13 is a third or more degree harmonic component, and I_4 is the output current of the high-pass filter 16. The output current I_4 of the high-pass filter 16 is a result of combining all the harmonics. The phase of the output current I_4 of the high-pass filter 16 is reversed by 180° at the phase reverser 17, and the resulting current I_4 is supplied to the automatic current regulator 18 as a reference current ($-I_4$).

On the other hand, the current sensor 14 serves to sense the current I_{c1} to be chopped in the switching section 11 and supply the sensed current I_{c1} to the automatic current regulator 18. The automatic current regulator 18 compares the sensed current I_{c1} with the reference current sent from the phase reverser 17 and controls the waveform of the current I_{c1} to be equal to the waveform of the reference current ($-I_4$) during the period when the reference current is flowing. That is, the automatic current regulator 18 and the chopping and combining circuit 19 defines such a conduction ratio of the switching section as establishing the equation of:

$I_{c1} = -I_4$ (2)

The chopping and combining circuit 19 serves to produce a pulse signal depending on a conduction ratio defined from a triangular wave signal output from the triangular wave generator circuit 20. Based on the pulse signal, the driving circuit 21 serves to control on and off the switching element included in the switching section 11.

Then, the equation (1) can be interpreted as follows:

$$\begin{aligned} I_s &= I_{c1} + I_{c2} \\ &= I_{c1} + \{\text{fundamental components of } I_{c2} + \text{harmonic components of } I_{c2}\} \\ &= I_{c1} + I_1 + I_4 \end{aligned}$$

Thus, from the equation (2)

$I_s = I_1$ = fundamental components of I_{c2}

It means that the a.c. load current I_s has a sine wave.

According to the above arrangement, if the a.c. load current I_s is partially lower than the reference current ($-I_4$), the automatic current regulator 18 serves to increase the conduction ratio of the switching elements T_{r1}, T_{r2}, T_{r3}, thereby keeping the load current sinusoidal.

According to this embodiment, the switching section 11 serves as cancelling the harmonic components of the current I_{c2}, so that the a.c. load current I_s is allowed to be constantly kept sinusoidal independently of the type and the magnitude of the load.

As is apparent from the above description, the triangular wave generator circuit 20 serves to define the maximum switching frequency of the switching element included in the switching section 11. Unlike the prior arts, therefore, part of the switching frequency is not allowed to be abnormally higher. It results in reducing the switching loss of the switching element.

Having described the smoothing section served as the load of the switching section, the similar control is made possible if the later stage of the current sensor or the output of the switching section is directly connected to another load such as a control power supply or another motor.

Further, the present embodiment has described that the current I_{c2} is sensed by winding a secondary coil around the inductor of the smoothing section. In place, the use of a hole element sensor makes it possible to directly sense the waveform of the current.

Fig. 4 shows a power supply according to another embodiment of the present invention. This embodiment is analogous to the embodiment shown in Fig. 1 except provision of an averaging circuit 51.

In Fig. 1, consider that the current sensors 14 and 15 have respective amplification factors or accuracies. In this case, an error appears about the compared result between the current I_{c1} and the reference current ($-I_4$) in the automatic current regulator 18. The appearance of the error results in having an adverse effect on the a.c. load current I_s. For example, if the current sensor 14 has a smaller amplification factor than the current sensor 15, the switching section 11 works to set a bit larger conduction ratio of the switching element, resulting in intensifying a three-degree harmonic, thereby distorting the waveform of the a.c. load current. Conversely, if the current sensor 14 has a larger amplification factor than the current sensor 15, the conduction ratio is set smaller, resulting in distorting the waveform of the a.c. load current as well.

To overcome this shortcoming the, in arrangement shown in Fig. 4, the current I_{c2} sensed by the current sensor 15 is averaged in the averaging circuit 51. The resulting averaged signal is used to control the amplification factor of the current sensor 14. Concretely, the amplification factors of the current sensors 14 and 15 may be controlled (for example, to be equal to each other) so that the a.c. load current I_s is made sinusoidal.

Fig. 5 shows a power supply according to another embodiment of the present invention. In place of the current sensor 15, the high-pass filter 16 and the phase reverser circuit 17 shown in Fig. 1, the averaging circuit 23 and the sinusoidal wave generator circuit 24 are used and the current sensor 14 is used for sensing the current I_s' output from the rectifying section 10.

The averaging circuit 23 serves to sense an average value of the current I_s' sensed by the current sensor 14. The sinusoidal wave generator circuit 24 serves to generate a sinusoidal wave current having the same frequency as the a.c. supply voltage V_s and the amplitude defined according to the averaged value and is sent as a reference current to the automatic current regulator 18. The automatic current regulator 18 serves to define such a conduction ratio for the switching element as matching the waveform of the current I_s' sensed by the current sensor 14 to that of the reference current.

According to the present embodiment, the conduction ratio is defined as monitoring the waveform of the current like the foregoing embodiments shown in Figs. 1 and 4. Hence, this embodiment has the same advantages as those foregoing embodiments. Further, this embodiment may be arranged to control the current waveform with low-capacitance switching elements if it has a plurality of switching elements connected in parallel and controlled on and off in sequence.

Fig. 6 is a circuit diagram showing a power supply according to another embodiment of the present invention. In Fig. 6, 4 is a capacitor, 25 is an inductor, D_{15} to D_{19} are diodes, T_a and T_b are transistors. The components corresponding to those shown in Fig. 1 have the same reference numbers.

In Fig. 6, the rectifying section 10 is composed of the diodes D_{15} to D_{18} for performing the full wave rectification of the a.c. supply voltage V_s. The switching section 11 is composed of an inductor 25 and two transistors T_a and T_b. The smoothing section 12 is composed of the diode D_{19} and the smoothing capacitor 4. The inductor 25, the diode D_{19}, and the smoothing capacitor 4 are connected in series between two output terminals of the rectifying section 10. The series connection of the diode D_{19} and the smoothing capacitor 4 is connected to the two transistors T_a and T_b connected in parallel.

Next, the operation of this embodiment will be described as referring to Fig. 7.

In case that the voltage charged in the smoothing capacitor 4 is lower than the output voltage of the rectifying section 10, the diode D_{19} is forward-biased and the transistors T_a and T_b are set off. It results in making the output voltage of the rectifying section 10 smoothed by the voltage charged in the smoothing capacitor 4 and applying the smoothed voltage as a d.c. supply voltage to the load 5. The voltage charged in the smoothing capacitor 4 depends on the magnitude of the load 5 and the constants of the inductor 25 and the smoothing capacitor 4. In general, however, the charged voltage is close to the a.c. supply voltage V_s.

In case that the voltage charged in the smoothing capacitor 4 is higher than the voltage output by the rectifying section 10, the diode D_{19} is reverse-biased. Hence, if the transistors T_a and T_b are not operative, no a.c. load current I_s flows and thus the a.c. load current I_s has a waveform containing lots of three-degree harmonics, resulting in lowering a power factor of the a.c. power supply 1.

To overcome this shortcoming, with the control circuit 101 using two systems of chopper circuits, the transistors T_a and T_b are controlled on and off in a manner that the transistors T_a and T_b are alternately switched on. In the area where the voltage output by the rectifying section 10 is high, the control circuit 101 serves to reduce the on-state period of the transistor T_a or T_b for reducing the switching loss.

With the transistor T_a or T_b being switched on, the current I_a or I_b flows from the rectifying section 10 to the inductor 25 and the transistor T_a or T_b, resulting in storing energy in the inductor 25. With the transistors T_a and T_b being switched off, the inductor 25 works to emit the stored energy as a high voltage. It results in being able to flow current from the inductor 25 to the diode D_{19}, the smoothing capacitor 4, the diode D_{17} or D_{18}, the a.c. power supply 1, and the diode D_{15} or D_{16}.

This operation makes it possible to flow the a.c. load current I_s when the output voltage of the rectifying section 10 is lower than the voltage charged in the smoothing capacitor 4. The transistors T_a and T_b are controlled on and off so that the a.c. load current I_s can have a sinusoidal waveform.

As mentioned above, this embodiment is arranged to alternately control the two transistors T_a and T_b on and off. The amount of current flown through each of the two transistors T_a and T_b is made smaller than the amount of current flown through a single transistor. It results in reducing the on-state voltage loss and the switching loss of the transistors T_a and T_b. It means that small-capacitance transistors may be used for the transistors T_a and T_b.

Though the number of the transistors used in the power supply is two, since those trnasistors have small capacitance, they can be accommodated as small-capacitance module components or a one-chip component in a single package. It results in reducing the overall power supply in size. The power supply according to this embodiment can be easily made from the conventional power supply in light of the circuit arrangement.

Fig. 8 is a circuit diagram showing a power supply according to another embodiment of the present invention. In Fig. 8, 26 and 27 are inductors and D_{20} is a diode. The components corresponding to those shown in Figs. 1 and 13 have the same reference numbers.

The present embodiment has the similar arrangement to the conventional power supply shown in Fig. 13 except that the current is supplied to the smoothing section through two current passages, that is, a current passage led from the rectifying section 10 and the other current passage composed of the inductor 27 and the diode D_{20} of the switching section 11. Concretely, this embodiment is arranged to provide in a rectifying section 10 an inductor 26 between an output terminal of the rectifying section 10 and cathodes of diodes D_1 and D_2 and in a switching section 11 another inductor 27 between cathodes of diodes D_5 and D_6 and a collector of the transistor T. The collector of the transistor T is connected to the output terminal of the rectifying section 10.

Next, the operation of this embodiment will be described.

In case that an absolute value of the a.c. supply voltage V_s is higher than a voltage charged in the smoothing capacitor 4, the transistor T is switched off, so that the a.c. supply voltage V_s is full-wave rectified by the full wave rectifying circuit composed of the diodes D_1 to D_4 of the rectifying section 10 and is smoothed in the smoothing capacitor 4. The smoothed voltage is applied as a d.c. supply voltage to the load 5. At this time, the charging current I_{c2} is flown from the diode D_1 or D_2 to the smoothing capacitor 4 through the inductor 26. The inductor 26 serves to remove high-frequency components such as noise from the charging current I_{c2}.

Consider that the absolute value of the a.c. supply voltage V_s is low enough to make the output voltage of the full wave rectifier circuit composed of the diodes D_1 to D_4 lower than the votlage charged in the smoothing capacitor 4. The diodes D_1 to D_4 are reverse-biased, resulting in reducing the current I_{c2} flowing through the inductor 26 to zero. The resulting current I_{c2} has a waveform containing lots of three-degree harmonics as shown in Fig. 9.

During the period when the smoothing capacitor is not charged, the transistor T is controlled on and off for chopping the current I_{c1} output from the full wave rectifier circuit composed of the diodes D_3 to D_6 included in the rectifying section 10. During the on-state period of the transistor T, the current I_{c1} is flown from the power supply 1 to the diode D_5 or D_6, the inductor 27, the transistor T, the diode D_4 or D_3. The inductor 27 stores the current I_{c1} as energy. During the off-state period of the transistor T, the inductor 27 emits the stored energy as a high voltage. It results in being able to flow the current I_{c1} from the inductor 27 to the diode D_{20}, the smoothing capacitor 4, the diode D_4 or D_3, the a.c. power supply 1 and the diode D_5 or D_6.

Fig. 9 shows the waveform of the current I_{c1} supplied by the above-mentioned operation. The a.c. load current I_s of the a.c. power supply 1 is a combined current of the currents I_{c1} and I_{c2}. The waveform of the a.c. load current I_s is close to a sine wave as shown in Fig. 9.

At a time point A of Fig. 9, consider that the current I_t flown when the transistor T is switched on and off in this embodiment is compared with the current I_t' when the transistor T is switched on and off in the embodiment shown in Fig. 13. In case that the charging current is supplied to the smoothing capacitor through a single current passage as in the embodiment shown in Fig. 13, the switching current is an added current of the switching current and the charged current as shown by a broken line of Fig. 9. Hence, the switching operation is performed for the large current I_t' as shown in Fig. 10.

However, the arrangement of a 2-path circuit as shown in Fig. 8 makes it possible to use only the current I_{c1} for the switching operation. It results in subtracting the charged current from the added current shown in Fig. 9, that is, being able to flow the current shown by I_t of Fig. 10 through the transistor.

Hence, the embodiment shown in Fig. 8 is capable of reducing the on-state voltage loss and the switching loss of the transistor T as compared with the embodiment shown in Fig. 13, resulting in reducing the capacitance and the size of the transistor T.

Fig. 11 is a circuit diagram showing a power supply according to another embodiment of the present invention. In Fig. 11, 25a and 25b are inductors, D_{19a} and D_{19b} are diodes, T_a and T_b are transistors. The components corresponding to those shown in the above-indicated drawings have the same reference numbers.

In Fig. 11, if the voltage charged in the smoothing capacitor 4 is lower than the output voltage of the full wave rectifier circuit composed of the diodes D_1 to D_4, the charging is done in the smoothing capacitor 4.

If the output voltage of the full wave rectifier circuit is lower than the voltage charged in the smoothing capacitor 4, the control circuit 101 serves to alternately control the transistors T_a and T_b on and off. The control circuit 101 contains two systems of normal chopper circuits. With the transistor T_a being switched on, the current is flown from the full wave rectifier circuit to the inductor 25a and the transistor. The current is stored as energy in the inductor 25a. With the transistor T_a being switched off, the inductor 25a emits the stored energy as a high voltage, resulting in being able to flow current from the inductor 25a to the diode D_{19a}, the smoothing capacitor 4, the diode D_4 or D_3, the a.c. power supply 1, and the diode D_1 or D_2.

Next, with the transistor T_b being switched on, likewise, the inductor 25b stores energy. With the transistor T_b being switched off, the inductor 25b emits the charged energy, resulting in being able to flow current from the inductor 25b to the diode D_{19b} andthe above components.

By repeating the above operations, the a.c. power supply 1 is capable of supplying the a.c. load current I_s having a waveform close to a sine wave.

Like the embodiment shown in Fig. 13, the power supply according to the present embodiment (Fig. 11) can lower the on-state voltage loss and the switching loss of the transistors T_a and T_b as compared to the power supply using a single transistor. It results in being able to reduce the capacitance and the size of the used transistors T_a and T_b.

Fig. 12 is a circuit diagram showing a power supply according to an embodiment of the present invention. In Fig. 12, 28a and 28b are inductors, D_{21a}, D_{21b}, D_{22a} and D_{22b} are diodes, and T_a and T_b are transistors. The components corresponding to those shown in Fig. 16 have the same reference numbers.

The present embodiment has the same arrangement as the conventional power supply using the voltage doubler rectifier circuit shown in Fig. 16, except that the inductors 28a, 28b, the diodes D_{21a}, D_{21b}, D_{22a}, D_{22b}, and the transistors T_a, T_b are provided in place of the diodes D_{12}, D_{14} and the transsitors T_A and T_B shown in Fig. 16.

As shown, two series circuits are provided in parallel to the a.c. power supply 1, one series circuit being composed of the inductor 28a, the diode D_{22a} and the npn type transistor T_a and the other series circuit being composed of the inductor 28b, the diode D_{22b} and the pnp type transistor T_b. The diode D_{21a} is connected between an anode of the diode D_{22a} and a cathode of the diode D_{11} and the diode D_{21b} is connected between a cathode of the diode D_{22b} and an anode of the diode D_{13}.

Next, the operation of this embodiment will be described.

During the period when the a.c. supply voltage V_s having a sinusoidal waveform is a relatively high, this embodiment operates in the same manner as the conventional power supply shown in Fig. 16. The smoothing capacitor 4A is charged during that period while keeping the a.c. supply voltage V_s at the positive polarity indicated by an arrow. The smoothing capacitor 4B is charged during that period while keeping the a.c. supply voltage V_s at a negative polarity opposite to the polarity indicated by the arrow. At this time, the transistors T_a and T_b are switched off.

The transistors T_a and T_b are controlled on and off by the control circuit 101 having two systems of normal chopper circuits.

With the transistor T_a being switched on, the current flows through the inductor 28a, the diode D_{22a} and the transistor T_a, resulting in storing energy in the inductor 28a. Then, with the transistor T_a being switched off, the inductor 28a serves to emit the stored energy as a high voltage, resulting in being able to flow current through the inductor 28a, the diode D_{21a}, the smoothing capacitor 4A, and the a.c. power supply 1. With the transistor T_b being switched on, the current flows through the transistor T_b, the diode D_{22b} and the inductor 28b, resulting in storing energy in the inductor 28b. Then, with the transistor T_b being switched off, the inductor 29b serves to emit the stored energy as a high voltage, resulting in being able to flow current through the inductor 28b, the a.c. power supply 1, the smoothing capacitor 4B and the diode D_{21b}.

While the transistors T_a and T_b are being controlled on and off, if an absolute value of the a.c. supply voltage V_s is higher than the voltage charged in the smoothing capacitor 4A or 4B, the effect of the energy-storing function of the inductors 28a and 28b brings the diodes D_{11} and D_{13} into a forward-biased state. it results in flowing part of the a.c. load current I_s through one of two loops, one loop composed of the a.c. power supply 1, the inductor 2A, the diode D_{11}, the smoothing capacitor 4A and the a.c. power supply 1 or the other loop composed of the a.c. power supply 1, the smoothing capacitor 4B, the diode D_{13}, the inductor 2A and the a.c. power supply 1.

Hence, this embodiment makes it possible to produce the a.c. load current I_s having a waveform closing to a sine wave. When the transistors T_a and T_b are controlled on and off if the a.c. supply voltage V_s is a relatively high, part of the a.c. load current is allowed to flow through the transistors T_a and T_b. It means that this embodiment is capable of reducing the on-state voltage loss and the switching loss of the transistors T_a and T_b as compared with the conventional power supply shown in Fig. 16 and using as the transistors T_a and T_b small transistors with low capacitance.

Claims

1. In a power supply including a rectifying section (10) for rectifying a sinusoidal a.c. voltage, a switching section (11) for supplying an output voltage of said rectifying section, and a smoothing section (12) having a smoothing capacitor, said switching section having an inductor and a switching element, said inductor storing energy from current output from said rectifying section during an on-state period of

said switching element and emitting said energy to said smoothing section during an off-state period of said switching element, said power supply having a capability of controlling load current to have a sinusoidal wave-form comprising:

(1) a first path for flowing current from said rectifying section to said smoothing section;

(2) a second path for flowing current from said inductor to said smoothing section;

(3) first current sensing means (15) for sensing the current (I_{c2}) flowing through said first path;

(4) current waveform forming means (16, 17) for forming a reference current having a target object from the current output from said first current sensing means;

(5) second current sensing means (14) for sensing current flowing through said switching element;

(6) means (18, 19, 20) for determining such a conduction ratio of said switching element as matching a waveform of an output current of said second current sensing means to a waveform of said reference current during a period when said reference current flows; and

(7) means (21) for controlling said switching element on and off based on said conduction ratio.

2. A power supply according to claim 1, wherein said means for forming a current waveform includes a high-pass filter (16) having a higher cut-off frequency than the frequency of said a.c. voltage.

3. A power supply according to claim 1, further comprising means (22) for setting both amplification factors of said first and second current sensing means to have a predetermined relation.

4. A power supply according to claim 2, further comprising means (22) for setting both amplification factors of said first and second current sensing means to have a predetermined relation.

5. A power supply according to claim 1, wherein said switching section (11) includes a plurality of switching elements (Tr_1, Tr_2, Tr_3) connected in parallel and said means for controlling said switching section on and off includes means (11) for switching sequentially said switching elements on and off.

6. A power supply according to claim 5, wherein said switching elements are accommodated as one chip or module in a package.

7. In a power supply including a rectifying section (10) for rectifying a sinusoidal a.c. voltage, a switching section (11) for supplying an output voltage of said rectifying section, and a smoothing section (12) having a smoothing capacitor, said switching section having an inductor and a switching element, said inductor storing energy from current output from said rectifying section during an on-state period of said switching element and emitting said energy to said smoothing section during an off-state period of said switching element, said power supply (Fig. 5) having a capability of controlling load current to have a sinusoidal waveform comprising:

(1) means (14) for sensing current flowing from said rectifying to said smoothing section;

(2) current waveform forming means (23, 24) for forming a sinusoidal reference current having an amplitude defined according to an average value of the output current of said current sensing means and a frequency equal to said a.c. voltage;

(3) means (18, 19, 20) for determining such a conduction ratio of said switching element as matching a waveform of an output current of said second current sensing means to a waveform of said reference current during a period when said reference current flows; and

(4) means (21) for controlling said switching element on and off based on said conduction ratio.

8. A power supply according to claim 7, wherein said switching section includes a plurality of switching elements connected in parallel and said means for controlling said switching section on and off includes means for switching sequentially said switching elements on and off.

9. A power supply according to claim 8, wherein said switching elements are accommodated as one chip or module in a package.

10. In a power supply including a rectifying section (10) for rectifying a sinusoidal a.c. voltage, a switching section (11) for supplying an output voltage of said rectifying section, and a smoothing section (12) having a smoothing capacitor, said switching section having an inductor and a switching element, said inductor storing energy from current output from said rectifying section during an on-state period of said switching element and emitting said energy to said smoothing section during an off-state period of said switching element, said power supply (Figs. 4 and 8) having a capability of controlling load current to have a sinusoidal waveform comprising:

(1) a first path for flowing current from said rectifying section to said smoothing section; and

(2) a second path for flowing current from said inductor to said smoothing section.

11. A power supply according to claim 10, wherein said switching section includes:

said plurality of switching elements connected in parallel; and

means for sequentially controlling said switching elements on and off.

12. A power supply according to claim 11, wherein said switching elements are accommodated as one chip or module in a package.

13. In a power supply including rectifying sections (D_1, D_2, D_3, D_4), a switching section for receiving the output voltage of said rectifying sections, and a smoothing section having a smoothing capacitor (4), said power supply having a capability of controlling a load current to have a sinusoidal waveform and said switching section being located between said rectifying section and said smoothing section, said switching section comprising:

(1) a circuit having two or more series circuits each composed of inductors (25a, 25b) and switching elements (T_a, T_b), said series circuits being connected in parallel;

(2) rectifier elements (D_{19a}, D_{19b}) connected to contacts between said inductors and said switching elements;

(3) a current path for supplying energy to said smoothing section through said rectifier elements; and

(4) means (101) for controlling said switching elements on and off.

14. A power supply according to claim 13, wherein said means for controlling said switching elements on and off includes means (101) for sequentially controlling said switching elements on and off.

15. In a power supply including voltage double rectifying sections (D_{11}, D_{13}) for rectifying a sinusoidal a.c. voltage, a switching section for receiving the output voltage of said voltage doubler rectifying section and a smoothing section having smoothing capacitors (4A, 4B), said power supply (Fig. 12) having a capability of controlling a load current to have a sinusoidal waveform and said switching section being located between said voltage double rectifying sections and said smoothing section,

said switching section comprising:

(1) a circuit having two series circuits each composed of an inductor (28a, 28b), a first rectifier element (D_{22a}, D_{22b}) and a switching element (T_a, T_b),said two series circuits being connected to an a.c. voltage generator (1) in parallel;

(2) a current path for supplying energy from a later stage of said inductors to said smoothing section through second rectifier elements (D_{21a}, D_{21b}); and

(3) means (101) for controlling said switching element on and off if the output voltage of said rectifying section is equal to or lower than a predetermined value.

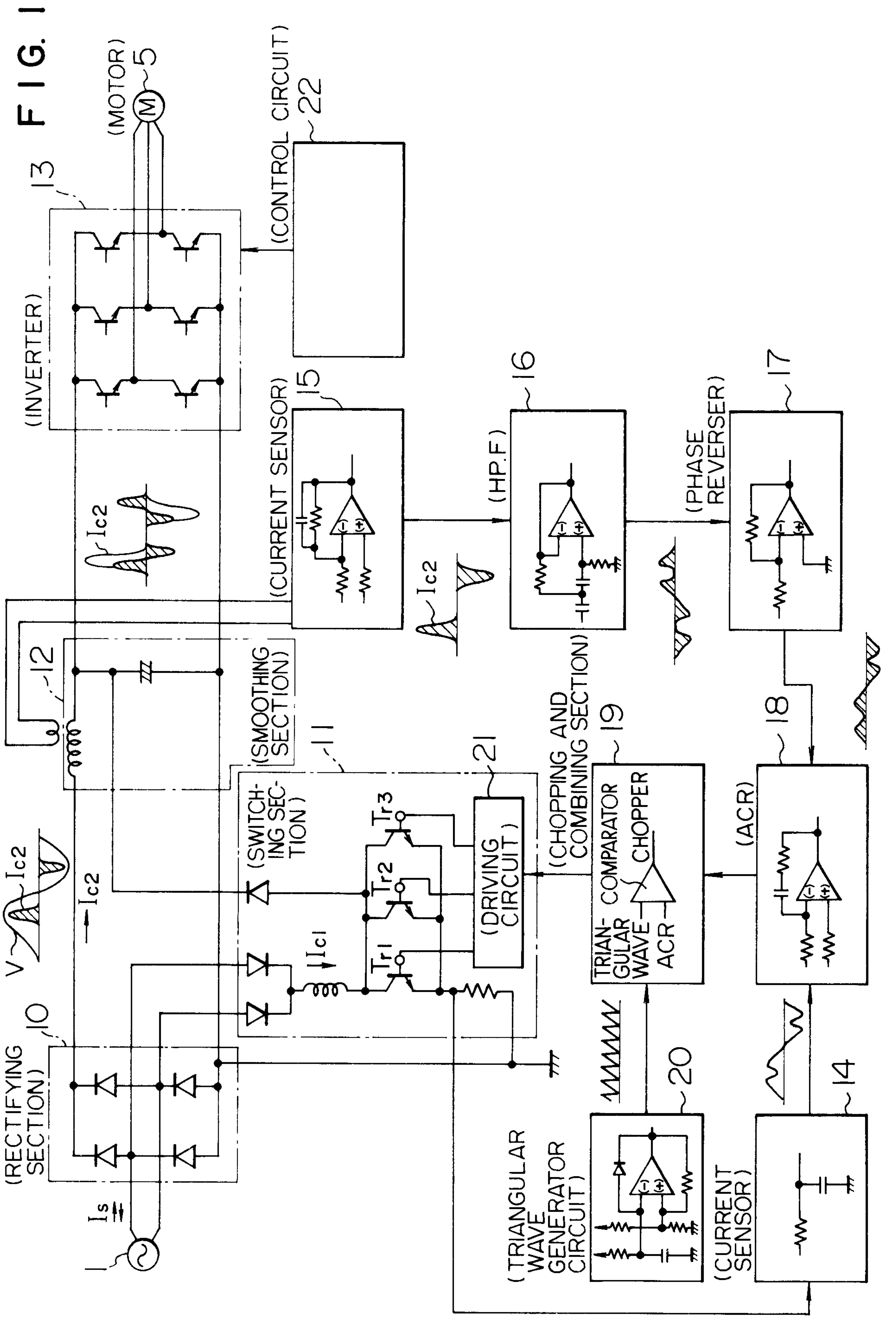
16. A power supply according to claim 15, wherein said means for controlling said switching element on and off includes means (101) for sequentially controlling said switching elements on and off.

17. In a power supply including a rectifying section (10) for rectifying a sinusoidal a.c. voltage, a switching section (11) for receiving a voltage output from said rectifying section (10), and a smoothing section (12) having a smoothing capacitor, said switching section having an inductor and switching elements (T_a, T_b), said inductor storing energy from the output current of said rectifying section during an on-state period of said switching element and emitting said stored energy to said smoothing section during an off-state period of said switching elements, said power supply (Fig. 6) having a capability of controlling a load current to have a sinusoidal waveform and said switching section comprising:

(1) a plurality of said switching elements (T_a, T_b); and

(2) means (101) for sequentially controlling said switching elements.

FIG. 1



(INVERTER)
13
(MOTOR)
M
5
(CONTROL CIRCUIT)
22
(CURRENT SENSOR)
15
(HP.F)
16
(PHASE REVERSER)
17
Ic2
12
(SMOOTHING SECTION)
11
(SWITCHING SECTION)
21
(DRIVING CIRCUIT)
Tr1
Tr2
Tr3
Ic1
Ic2
V
10
(RECTIFYING SECTION)
Is
1
(CHOPPING AND COMBINING SECTION)
19
COMPARATOR
CHOPPER
TRIANGULAR WAVE
ACR
18
(ACR)
20
(TRIANGULAR WAVE GENERATOR CIRCUIT)
14
(CURRENT SENSOR)

FIG. 2

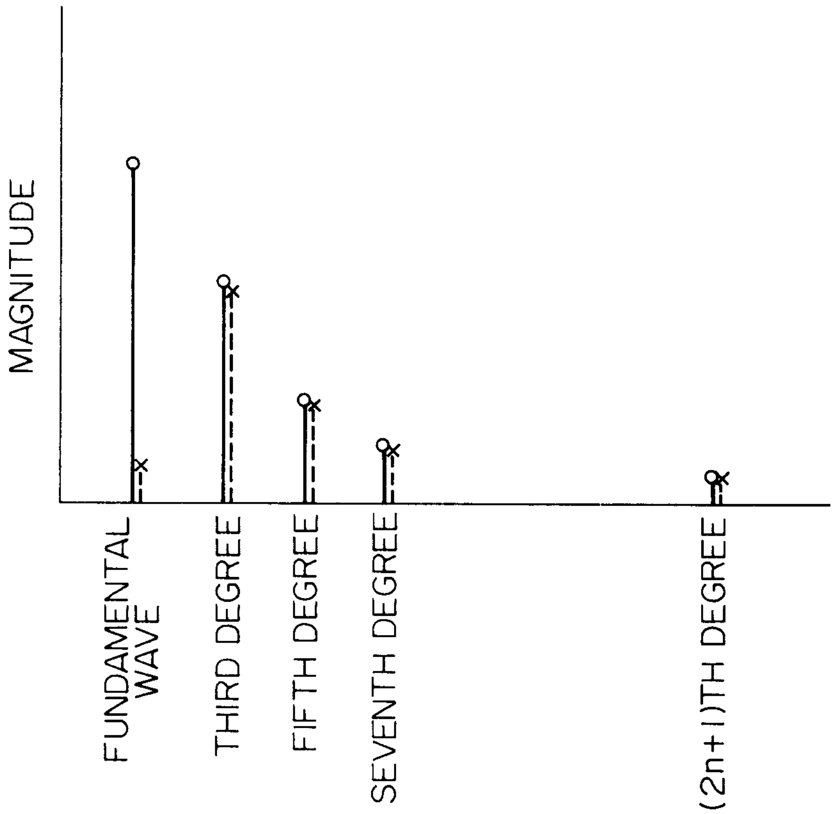

MAGNITUDE
FUNDAMENTAL WAVE
THIRD DEGREE
FIFTH DEGREE
SEVENTH DEGREE
(2n+1)TH DEGREE

FIG. 3

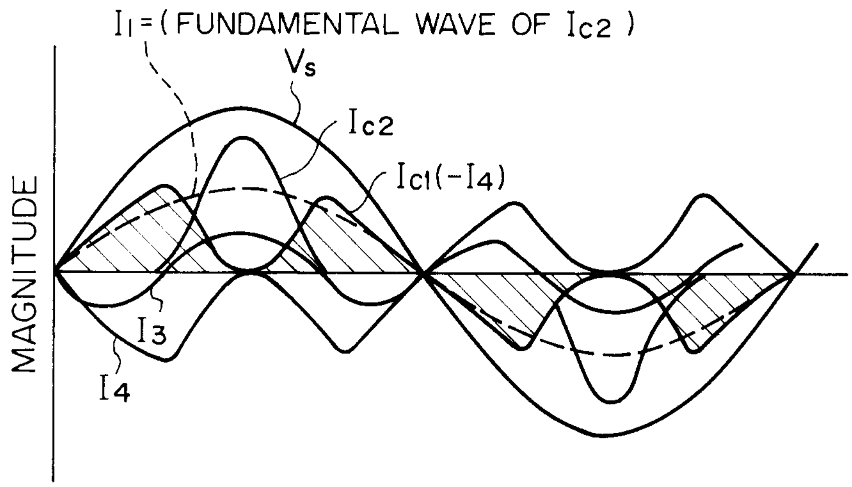

I1 = (FUNDAMENTAL WAVE OF Ic2)
Vs
Ic2
Ic1(-I4)
MAGNITUDE
I3
I4

FIG. 4

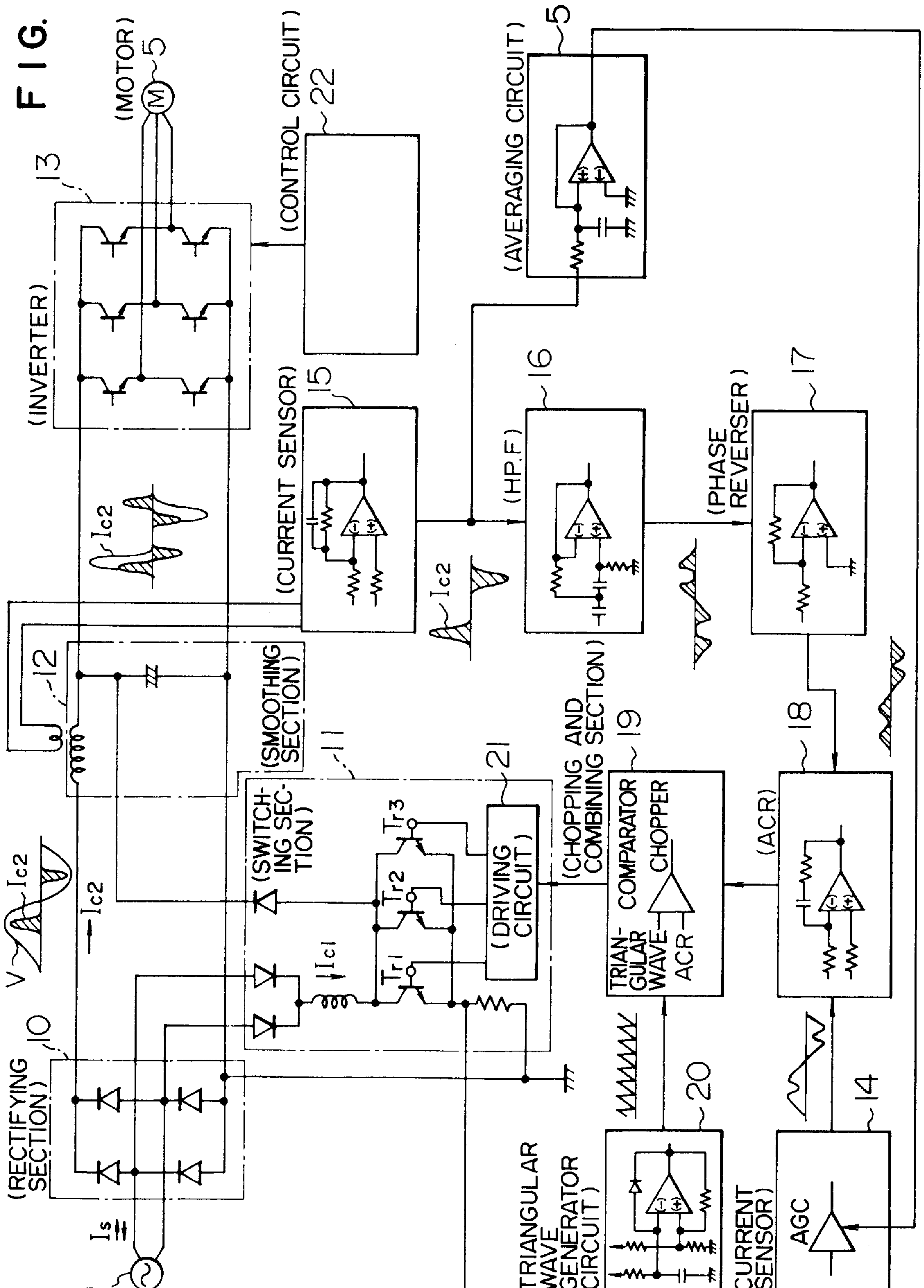
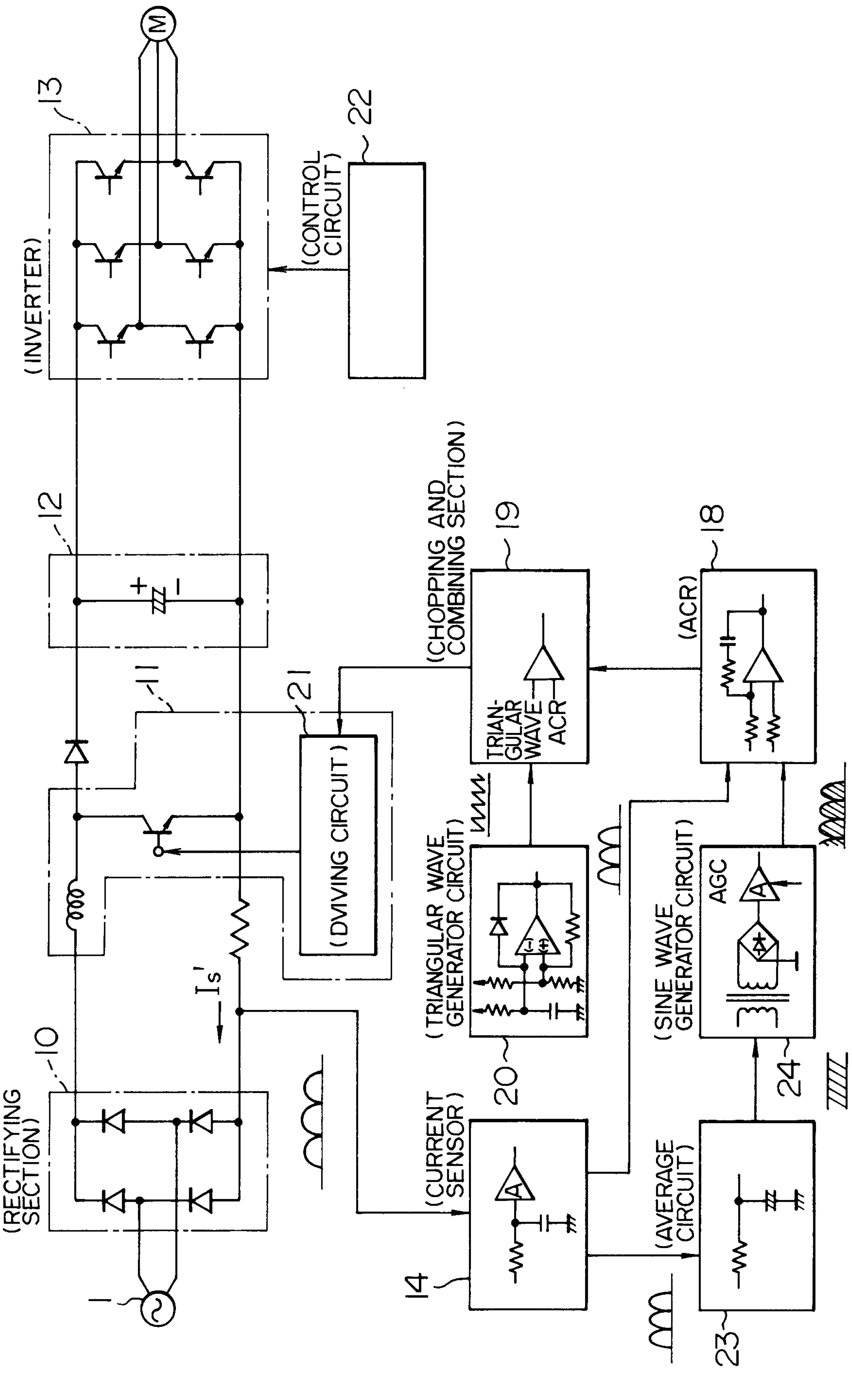
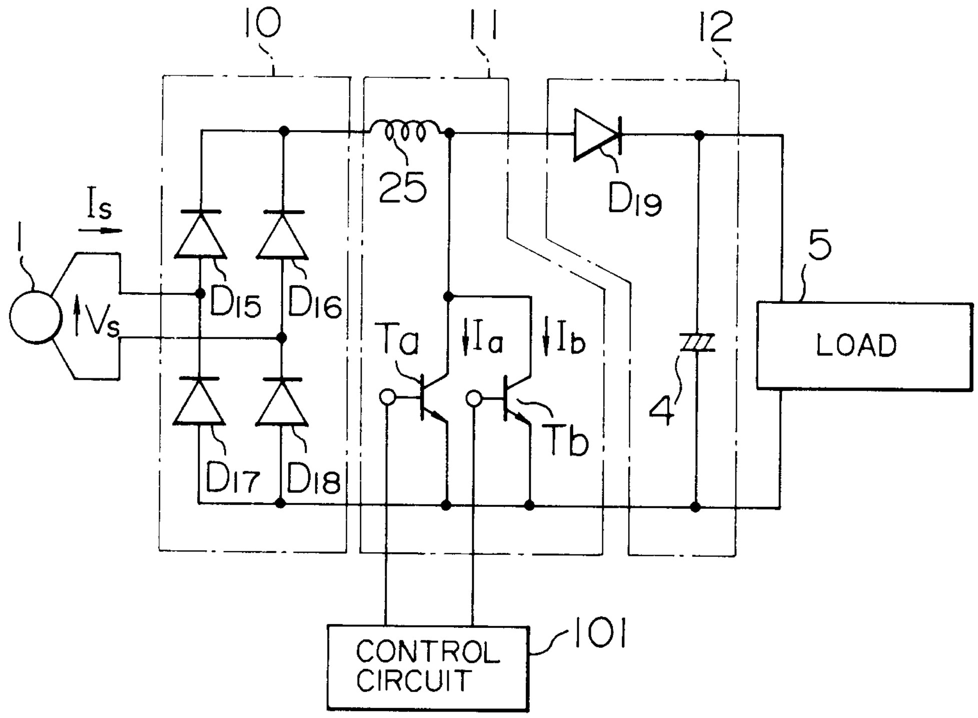

(MOTOR)
5
13
(INVERTER)
(CONTROL CIRCUIT)
22
(AVERAGING CIRCUIT)
51
(CURRENT SENSOR)
15
(HP.F)
16
(PHASE REVERSER)
17
Ic2
12
(SMOOTHING SECTION)
11
(SWITCHING SECTION)
(CHOPPING AND COMBINING SECTION)
19
COMPARATOR
CHOPPER
TRIANGULAR WAVE
ACR
(ACR)
18
21
(DRIVING CIRCUIT)
Tr1
Tr2
Tr3
Ic1
V
10
(RECTIFYING SECTION)
Is
20
(TRIANGULAR WAVE GENERATOR CIRCUIT)
14
(CURRENT SENSOR)
AGC

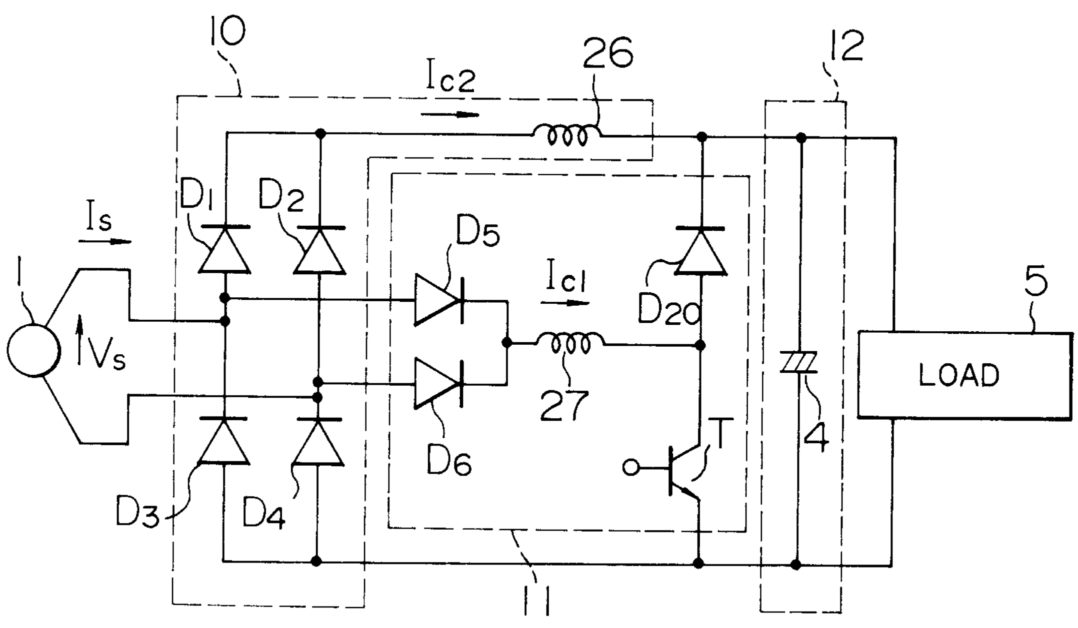
FIG. 5


(RECTIFYING SECTION)
10
1
11
12
13
(INVERTER)
M
(CONTROL CIRCUIT)
22
(DVIVING CIRCUIT)
21
Is'
(CURRENT SENSOR)
A
14
(TRIANGULAR WAVE GENERATOR CIRCUIT)
20
(CHOPPING AND COMBINING SECTION)
TRIAN-GULAR WAVE
ACR
19
(ACR)
18
(SINE WAVE GENERATOR CIRCUIT)
AGC
A
24
(AVERAGE CIRCUIT)
23

F I G. 6


10
11
12
25
D19
Is
1
D15
D16
5
Vs
Ta
Ia
Ib
LOAD
4
Tb
D17
D18
CONTROL CIRCUIT
101

F I G. 8


10
Ic2
26
12
D1
D2
Is
D5
Ic1
1
D20
5
Vs
27
LOAD
4
T
D6
D3
D4
11

F I G. 7

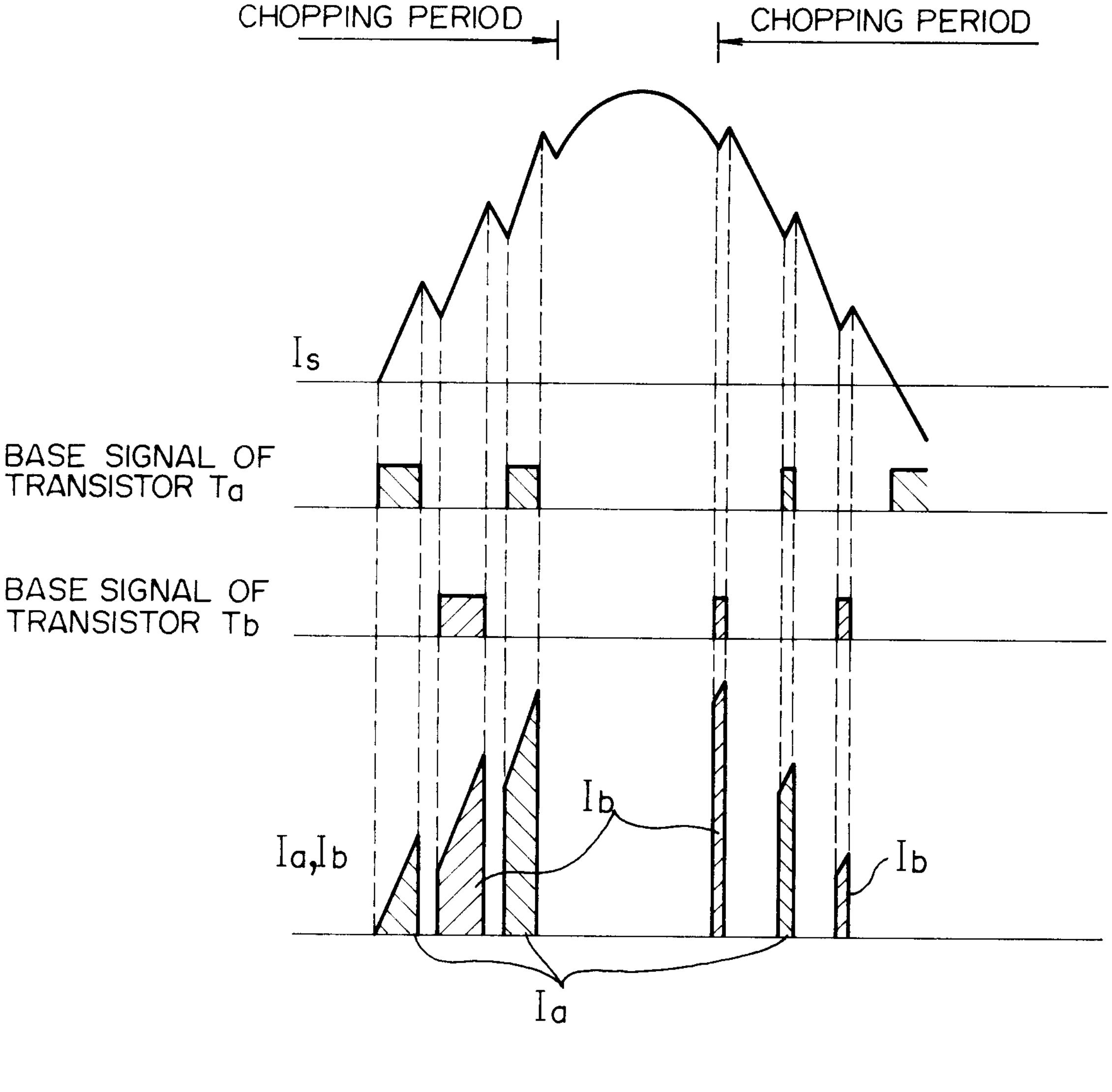

CHOPPING PERIOD
CHOPPING PERIOD
Is
BASE SIGNAL OF TRANSISTOR Ta
BASE SIGNAL OF TRANSISTOR Tb
Ia,Ib
Ib
Ib
Ia

FIG. 9

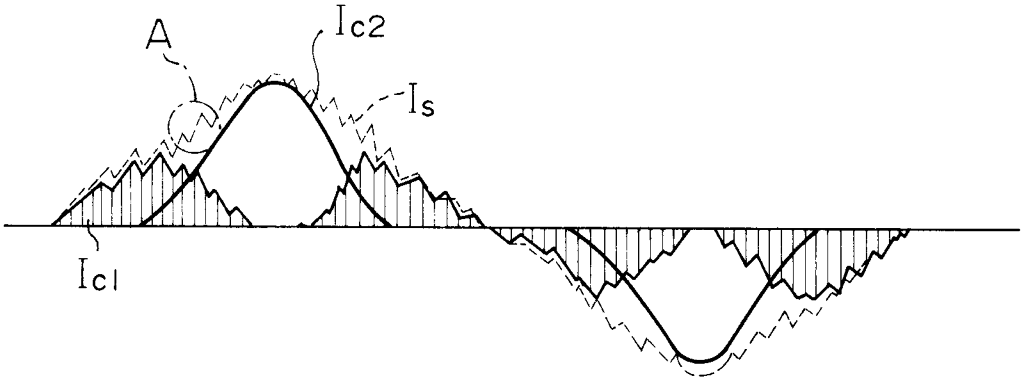
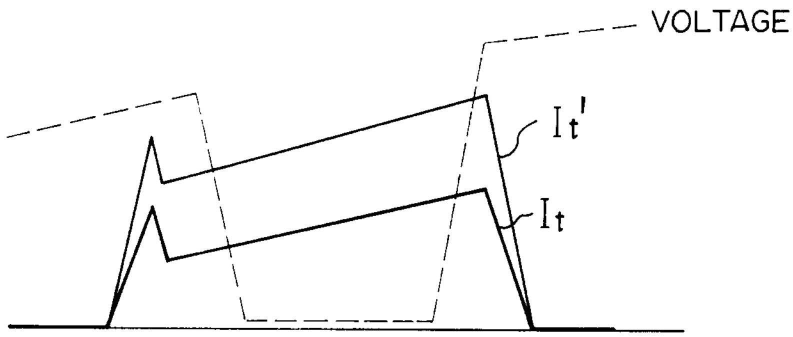
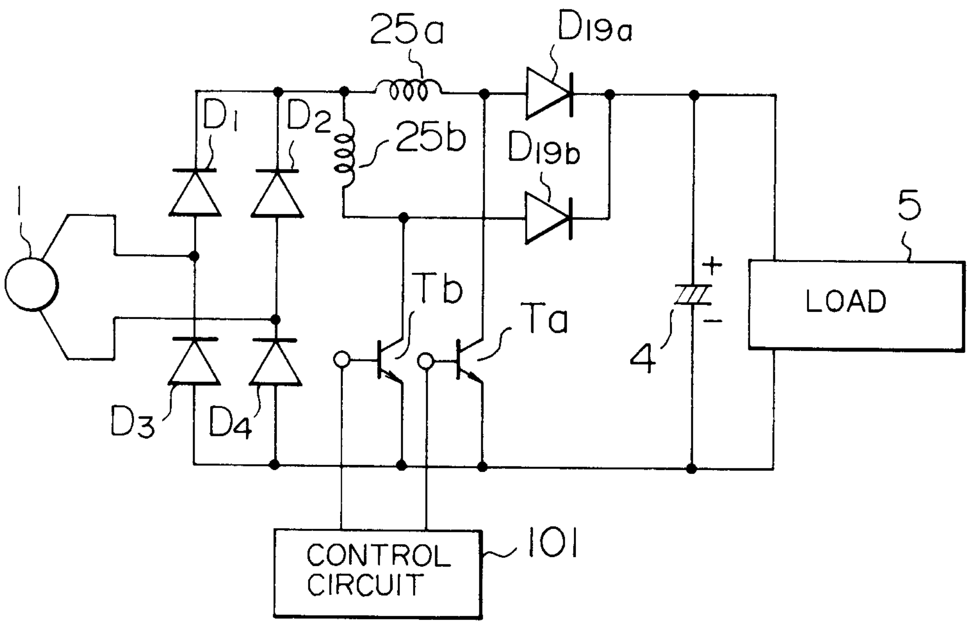


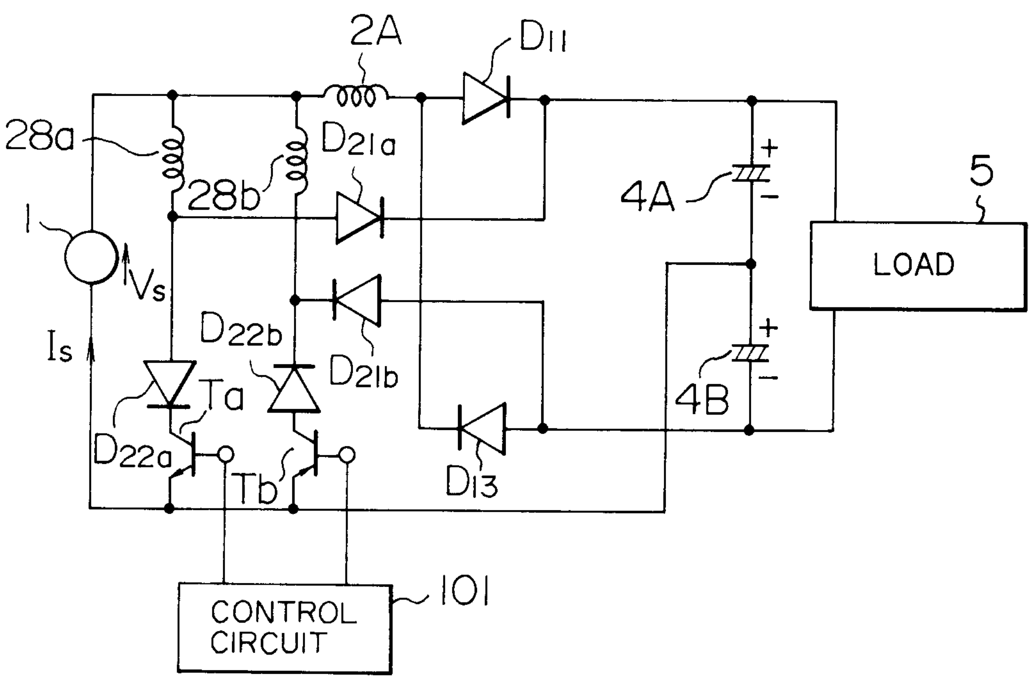
FIG. 10



F I G. 11


25a
D19a
D1
D2
25b
D19b
1
5
Tb
Ta
LOAD
4
D3
D4
CONTROL
CIRCUIT
101

F I G. 12


2A
D11
28a
D21a
28b
1
4A
5
Vs
LOAD
D22b
Is
D21b
Ta
4B
D22a
Tb
D13
CONTROL
CIRCUIT
101

F I G. 13
PRIOR ART

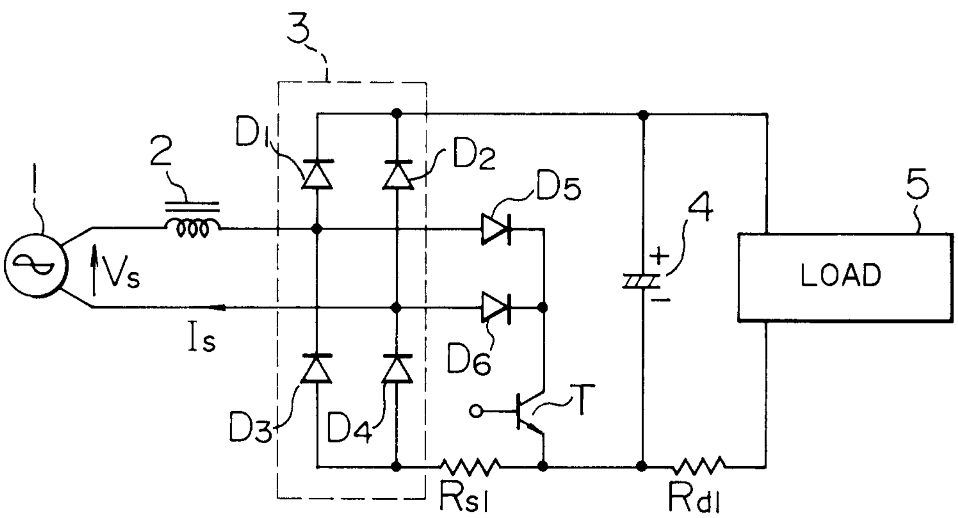
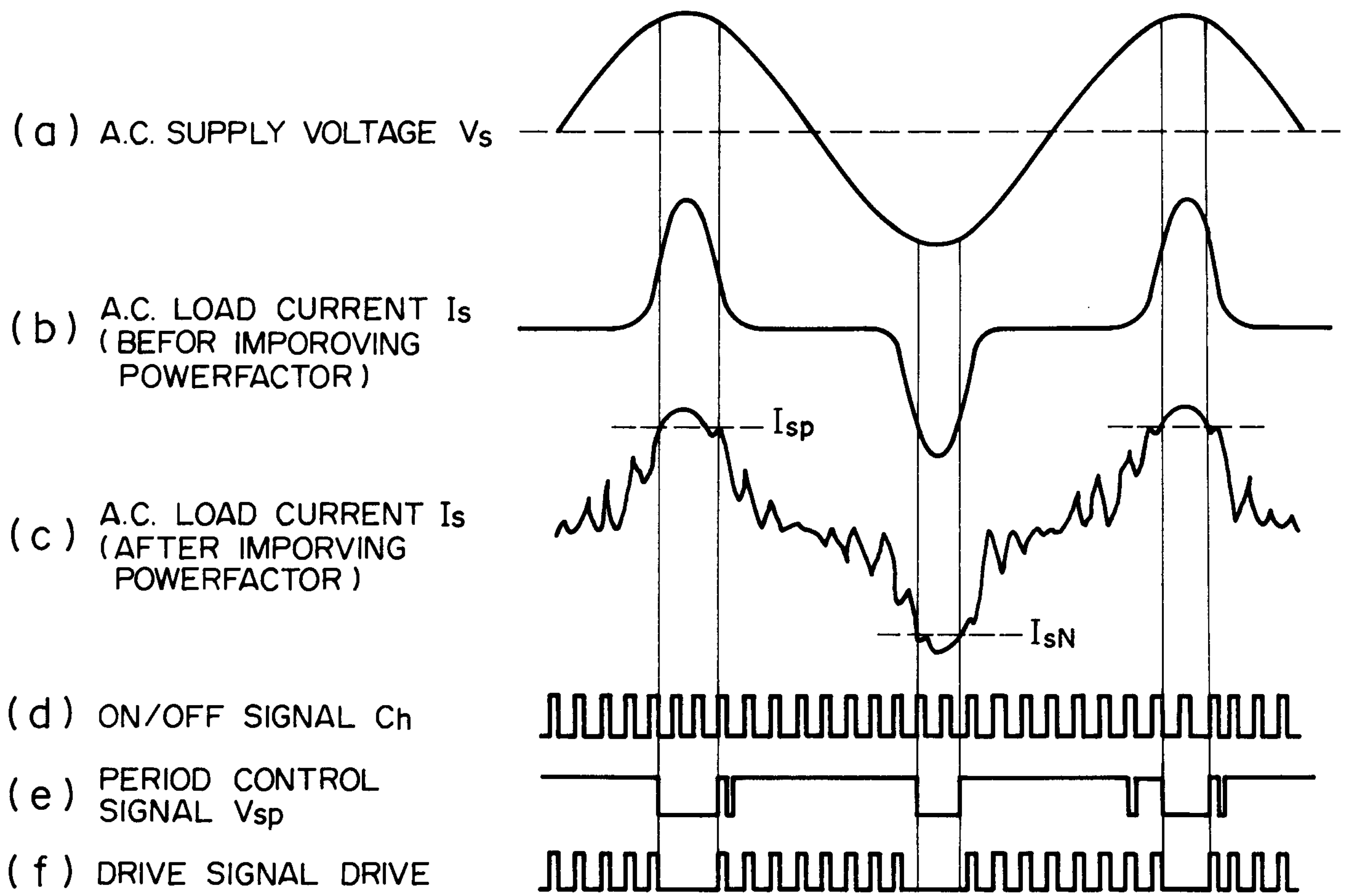
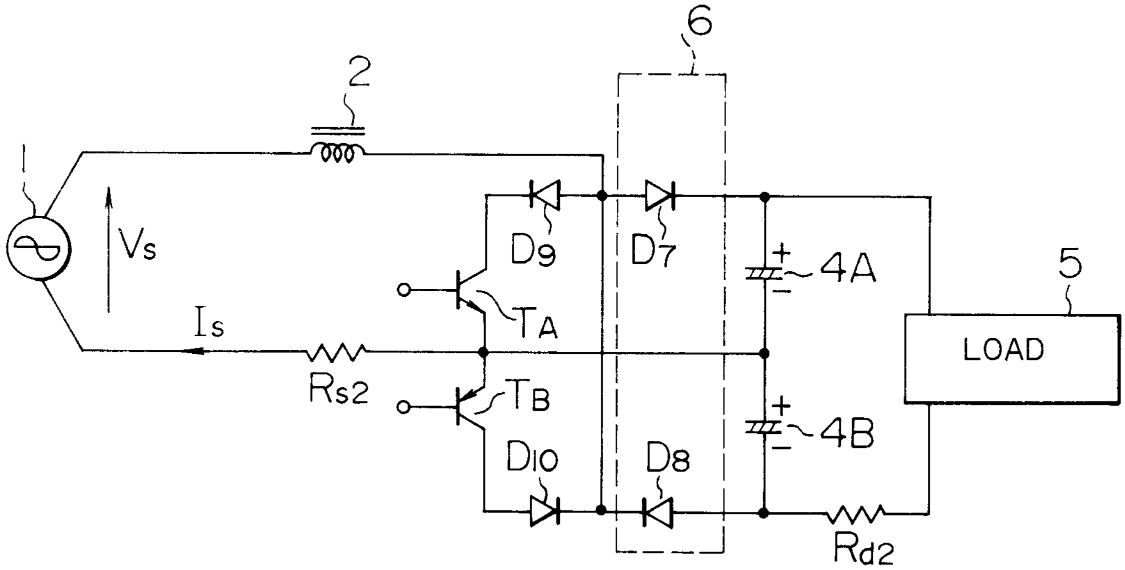


FIG. 14
PRIOR ART



F I G. 15
PRIOR ART



F I G. 16
PRIOR ART

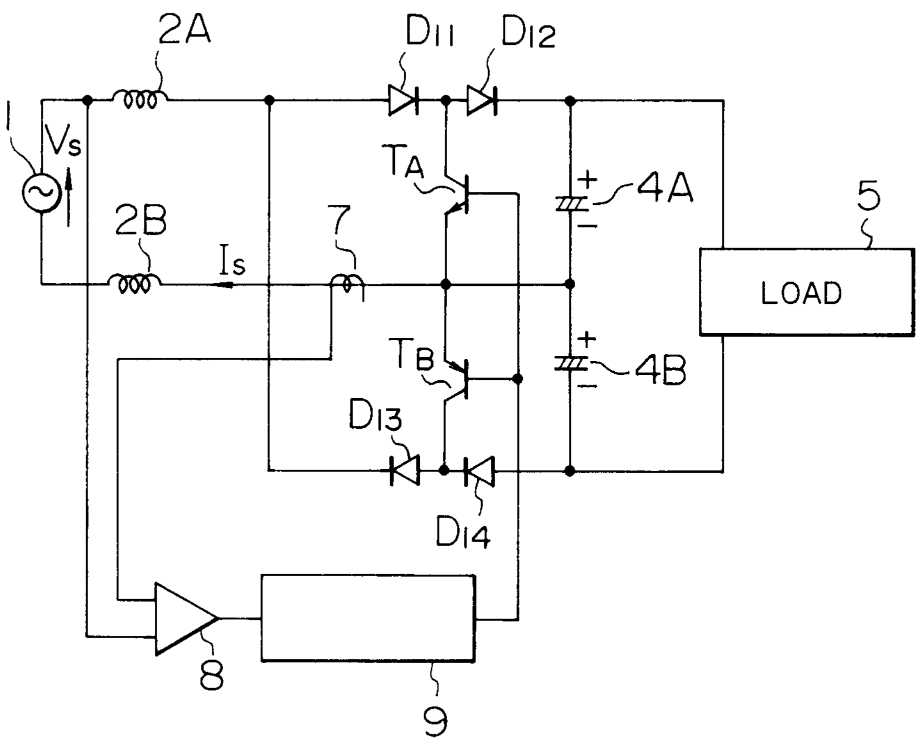


FIG. 17
PRIOR ART